

## Sky Access versus Shading for Pedestrian Comfort in the Hot Tropical Climate of Jeddah

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**Abstract:** *Many urban studies have been done to demonstrate that urban sprawl is not the right approach in hot climate cities. On the contrary, a compact design is recommended to enhance human thermal comfort. This research aims to clarify the relation between urban morphology and outdoor thermal comfort of Jeddah, Saudi Arabia. The aim is to develop an outstanding future strategic compact morphology that would facilitate a dynamic development of the city.*

*Jeddah city will soon have a subway that is expected to radically change the habits of its inhabitants. Our idea is to consider the main stations of the future metro as nodes, creating more densely inhabited localities and also defining transitional spaces for pedestrian activities. Microclimates generated in and around these activity nodes must be particularly studied to encourage residents and visitors to reclaim a pedestrian life that was clearly noticeable in the old city, but has virtually disappeared in most recent neighborhoods, entirely devoted to automobile transport. Services and facilities around metro nodes should become the transitional thermal comfort areas of the metro station exits.*

*This paper will provide numerical modeling simulations that are used to assess the solar radiation in the urban layout (the old compact area and the modern sprawl area) by the software "Heliodon 2" (direct shortwave, Sky View Factor) and "Heliodon plus" (climatic data) to clarify the differences between the old and the new layout and why the change to compactness needs to be put into effect.*

## 1 Introduction

Every year, the Saudi Arabian population is increasing by about 2% and the energy demand by 4–5% [Al-Hadhrami 2013]. Due to a rapidly escalating population and a high level of economic growth, the Kingdom of Saudi Arabia is experiencing a strong infrastructure expansion [Taleb 2015]. However, more than half of the country's energy demand has been created by the increased urban density together with the rise of consumerism, and these have not only led to an increase in environmental degradation locally, but they have also meant that the country's traditional primary energy is under used and consequently carbon emissions are set to rise and to play a larger role in global climate change. Electricity generation in Saudi Arabia is completely dependent on the unsustainable practice of burning fossil fuels, which has major environmental consequences.

However, when compared to other countries, the issue of energy efficiency is not generally given serious consideration with regard to Saudi urban building designs. In addition, the Kingdom of Saudi Arabia is one of the driest regions in the world and is facing serious challenges relating to a rapid growth [Kamal 2014]. Last, but not least, there are no regulations, or compulsory building codes, that incorporate the principles of sustainable architecture in the country [Taleb 2015]. It has been argued by many scholars that setting a coherent set of these codes and standards is one of the most important and cost-effective ways to promote the widespread of sustainable practices [Awawdehl 2014].

The government has adopted concepts and solutions from western nations in its architecture and physical planning. Rapid changes have taken place in the Kingdom of Saudi Arabia following the discovery of oil in commercial quantities and the country's opening up to the western world. The speed with which development has occurred and the rapid advance in technology experienced in the seventies, in every field, including construction, planning, industry, education, etc., have affected all aspects of living in the country. One aspect of life which has suffered most has been the traditional environment. The attraction of the western way of life and the western concept of development have drawn Saudi attention away from the development of a clear understanding of their traditional residential environment, and away from the value of its continuity.

With the introduction of automobiles, new building techniques and materials, the whole urban fabric of the city has been changed. A completely new form of housing has emerged and new physical communication networks have become necessary to accommodate the new mechanical means of transportation, with different housing types, wide dual carriageway roads, street intersections, flyovers and large areas of car parking spaces. Moreover the indigenous society has changed from being a highly traditional Islamic society into a semi-cosmopolitan environment of the twentieth century [Alharbi 1989].

According to [Brown 2010], many outdoor urban environments, especially in hot countries, tend to be poorly regulated and not thermally comfortable. [Lin 2009] indicated that few people visit squares or other public spaces in hot and humid regions when the thermal index is high.

During the day, the incoming solar (short-wave) radiation increases the surface and air temperatures. At night the surface is cooled due to the net outgoing long-wave radiation. This outgoing long-wave radiation diminishes with lower SVF, (higher H/W ratio). In concise terms, the narrower a street is, the less heat will be gained during the day, and less heat will be lost at night. [AL-Asir 2009]

From ancient times, a key strategy for thermal comfort and pollution dispersal in hot climates has been to maximise airflow and thereby achieve maximum ventilation. However, the low levels of wind speeds in the tropics during the passing of the inter-tropical

convergence zone twice a year make it necessary to carefully map out the ventilation strategy at a citywide level to induce sufficient air movement, both for pollution dispersion as well as thermal comfort. It will also enhance the cooling potential of naturally ventilated buildings (which is the common approach to indoor cooling in the warm, humid tropics)[AL-Asir 2009, Beckers 2012].

[Dalman, 2011] evaluated the microclimate principles of two different fabrics, one traditional and the other modern in the South East of Bandar Abbas. The study affirms the important following findings: canyon orientation, with effective shade and ventilation, was found to be the main contributor to thermal comfort in the selected area. In this regard, the usual wind and sea breeze, in combination with canyon orientation, play a significant role in providing a thermally comfortable situation. The streets height to width ratio (H/W ratio) in traditional fabrics is higher than in the modern one, and the traditional fabric was found to be more thermally comfortable. Hence, Shading and ventilation factors are not embedded in the design process in the modern fabrics of Bandar Abbas, which reveals scant consideration for these factors. The calculated values of thermal comfort indices (Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV), Standard Effective Temperature (SET) and Mean Radiant Temperature (MRT)) show a lower ratio in modern fabrics than in traditional areas; this is the effect of the lower H/W ratio and inadequate wind circulation and shading.

[Radhi2013] Investigates urban expansion in Bahrain over the last few decades and assesses its impact on atmospheric urban heat islands. The results show that network grids with structure and high density building developments that increase shelter and reduce wind velocity can lead to higher levels of stored heat on surfaces.

One of the most important urban parameters which affect solar access is urban density [Sanaieian 2014]. [Johansson 2006] examined the influence of urban geometry on outdoor thermal comfort by comparing an extremely deep street canyon and a shallow one in Fez, Morocco, making a comparison between an old and a new area. Continuous measurements during the hot summer and cool winter seasons show that, by day, the deep canyon was considerably cooler than the shallow one. The results indicate that, in hot dry climates, a compact urban design with very deep canyons is preferable.

## **2 Jeddah and its Climate**

### **2.1 Jeddah:**

The city of Jeddah is located in the western part of Saudi Arabia, where it overlooks the east coast of the Red Sea. With 3.9 million of inhabitants, Jeddah is considered the second largest city in Saudi Arabia in terms of population after Riyadh city. Jeddah is the most important seaport of Saudi Arabia on the Red Sea.

The history of Jeddah as a place of pilgrimage contributed to the development of its urban pattern. The rapid growth in population (natural and transient) in the last four decades coincided with the Kingdom's huge increase in wealth. This resulted in Jeddah City expanding physically at an unprecedented rate. This expansion was in part due to the limited success of spatial planning and regulatory frameworks that attempted to constrain development to certain areas of the city.

Without effective regulation and a coordinated, strategic approach, the urban area of Jeddah grew beyond the capacity of its infrastructure, leading to structural problems in the provision of water, sewage and roads. This growth also left the city with a number of structural challenges, including large quantities of vacant land and a dependency on the private car. Insensitive development, pollution, high energy consumption and lack of awareness damaged Jeddah's marine environment, while the relics of Jeddah's remarkable

heritage, in particular Albalad (la Medina) fell into decline [Khan 2012, Habibullah 2014, Fatta 2014].

## 2.2 Climate:

The city is located at latitude  $21^{\circ} 32'$  North,  $39^{\circ} 10'$  East. It has a hot climate, the Average Low/High temperatures usually vary between  $18^{\circ}\text{C}$  and  $39^{\circ}\text{C}$ , rarely going below  $16^{\circ}\text{C}$  or above  $41^{\circ}\text{C}$ . There are almost only clear skies, with cloud cover varying between 2% and 18%; the relative humidity varies between 30% and 89%, so the air is mostly humid. Rainfall in Jeddah is generally sparse, and usually occurs in small amounts in November and December, According to the Holdridge life zone system of bioclimatic classification, Jeddah is close to the tropical desert scrub biome (Khan 2012).

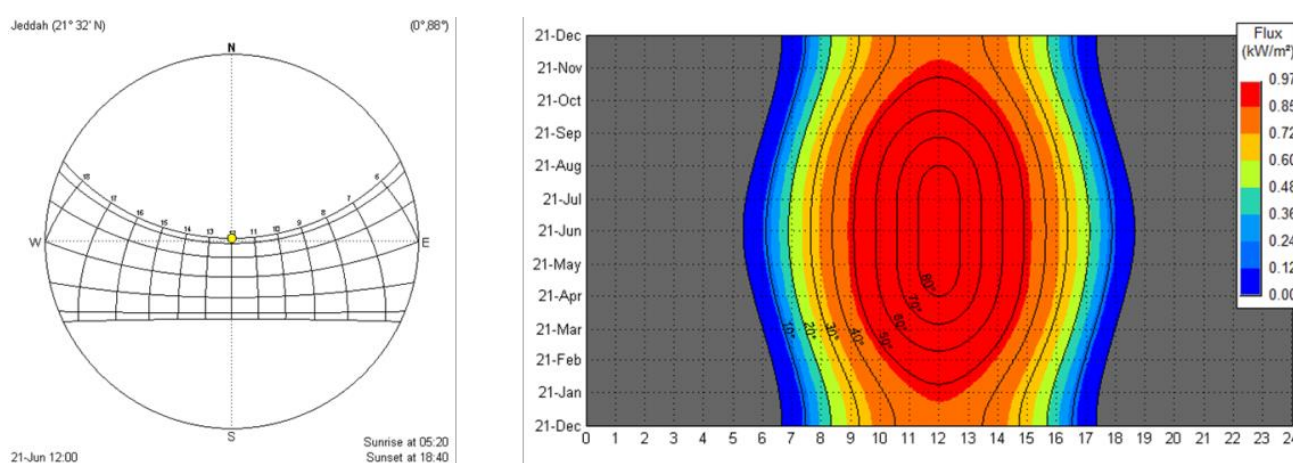


Figure 1: stereographic and isochronal solar diagrams for Jeddah

	Sunrise	Sunset	Solar height at noon
21 June	05:20	18:40	$88^{\circ}$
21 December	06:40	17:20	$45^{\circ}$

Table 1: Sunrise, Sunset and solar height at noon for 21<sup>st</sup> June and 21<sup>st</sup> December.

Jeddah is very close to the Tropic of Cancer. As shown in Table 1, the sun almost reaches the zenith in the summer solstice, reaching  $45^{\circ}$  at the winter solstice. The difference in day length between the two solstices is two hours and forty minutes. As shown on the isochronal projection of Figure 1 [Beckers, 2006], solar height is up to  $40^{\circ}$  between 10:30 and 13:30 during the entire year, and the direct radiation is then up to  $800 \text{ kW/m}^2$  in sunny hours, reaching  $1000 \text{ kW/m}^2$  in summertime.

[Khan & Duris, 2012] Studied Jeddah, Saudi Arabia urban structure and the amount of solar energy registered at ground level. Results have shown that the values of solar energy tend to be higher in the modern urban fabric than in the old one because of the significant differences between these two areas. These results show that modern districts with straight streets and large avenues receive more energy than the old city with its curved and narrower streets. The wider the street is, the easier it is for the sunlight to penetrate it. The fact that the modern city has almost only straight streets and avenues allows solar radiation to penetrate,



whilst the old city has narrower and more curved streets that cast enough shadow to considerably reduce direct sunlight.

### 3 Case studies:

#### 3.1 Description:

Two areas of Jeddah have been chosen for the analysis, according to their contrasting morphology. The first one is in the south part of Jeddah, which is the old area (Albalad). The second area is in the north part of Jeddah, which represents the modern urban layout of the city (Al Salamah district).

As shown in Figure2, both chosen urban patterns have distinctive characteristics, related to density, H/W ratios and building organization.

The old area is characterized by its narrow streets, with a width varying between 2m and 5m. Building heights are from one to six levels. It is a mixed use urban area (residential and commercial). The old area has a dense, compact and irregular pattern.

The selected case in the modern area is residential. The housing in Al Salamah district consists of two storey detached villas and apartment buildings ranging from five to seven stories. The typical lot size is 20 x 30 meters and most blocks are 60 x 180 meters. The district was laid out in a rectangular grid system, with rectangular and square lots. Such development consists of parallel alignments, simple geometrically shaped patterns of streets designed for adequate vehicle movement, with width ranges from 10 to 20 meters. The architecture is distinctly American in style and built according to zoning regulations that stipulate distances from the street, detached rather than attached buildings.

The simulation and analysis will be done on two intersecting streets on the two layouts (the old and new) The analysis in the modern area will take place in the apartment building zone, which has been selected because it is denser than the villa areas.

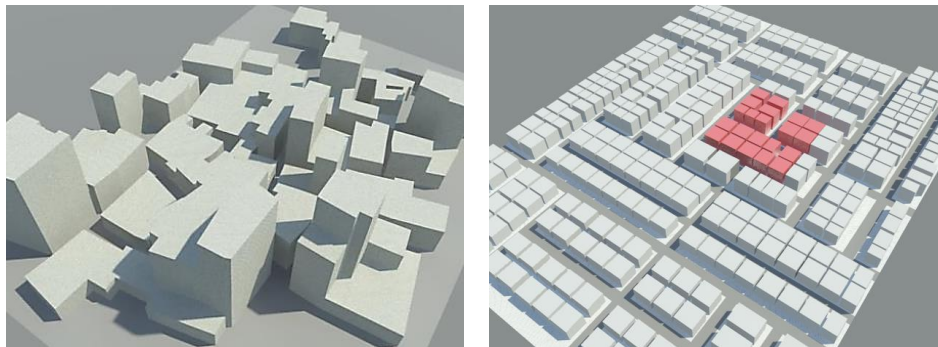


Figure 2: The 3D modeled on Rvrit Autodesk 2016 on the old area (Al Balad) and the modern area of Jeddah (Al Salamah)

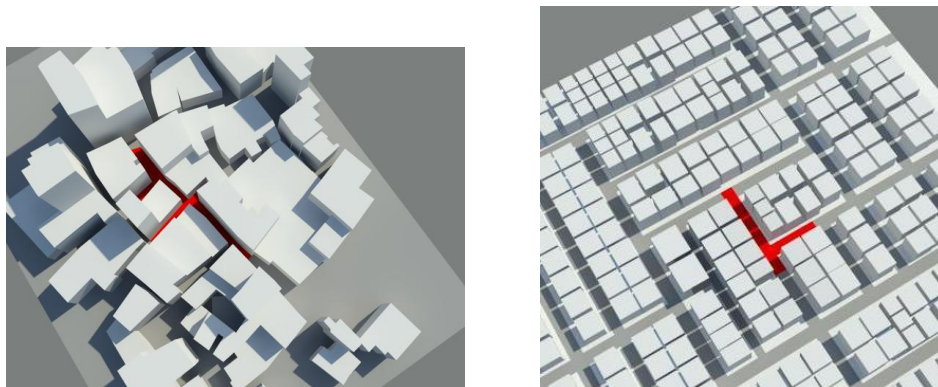


Figure 3: The 3D modeled on Rvrit Autodesk 2016 on the old area (Al Balad) and the modern area of Jeddah (Al Salamah) with the chosen intersection streets

### 3.1 Methodology:

The main analysis is realized with the Heliodon 2 software [Beckers 2006]. The program performs calculations in theoretical cloudless conditions, without taking into account the diffuse radiation emitted by the sky, nor the radiation reflected from nearby surfaces. It is completed by computations with the Heliodon Plus tool [Nahon 2016], which allows taking into account the climatic data.

## 4 Results:

### 4.1 Case study 1: old city urban layout:

The old area, as shown in Figure 4, has a mean sky view factor of 10.3%. Moreover, in Figure 5, we have a mean radiation value of three hours of sun in summer at street ground level, and only half an hour in winter.

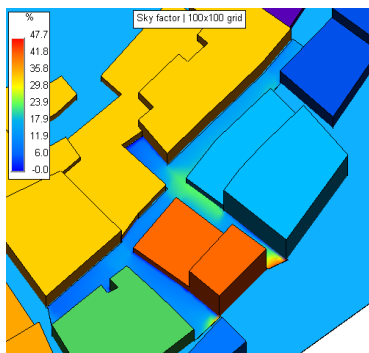


Figure 4: Mean SVF.

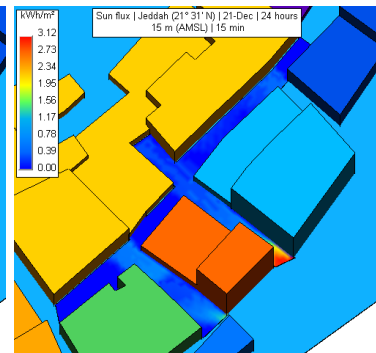
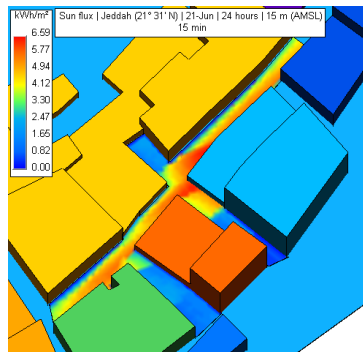


Figure 5: Mean Solar radiation value on 21<sup>st</sup> June and 21<sup>st</sup> December

Mean Solar period in summer	3h09 (429m <sup>2</sup> )
Mean Solar period in winter	0h31 (429m <sup>2</sup> )
Mean Sky view factor (SVF)	10.3%

Table 2: Old area Heliodon calculation (Mean Solar period on 21<sup>st</sup> June (Summer) and 21<sup>st</sup> Dec (Winter) and Mean SVF)

### 4.2 Case study 2: modern city urban layout

The modern area, as shown in Figure 6, has a mean sky view factor of 23.5%. Moreover, in Figure 7, we have a mean radiation value of six hours of sun in summer at street ground level, and only one hour in winter.

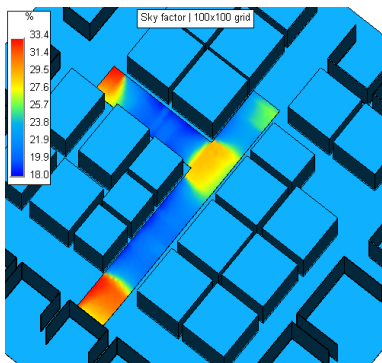


Figure 6: Mean SVF.

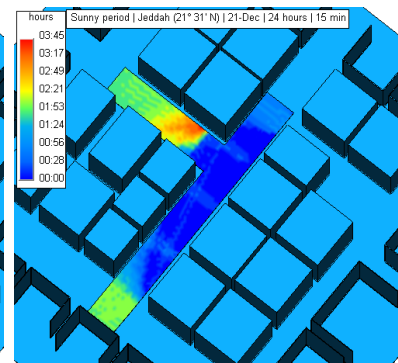
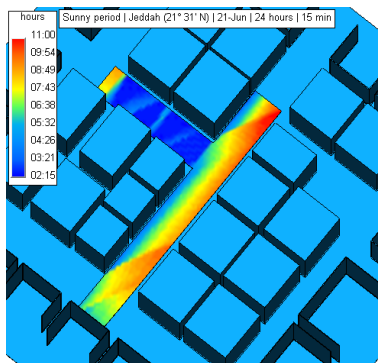


Figure 7: Mean Solar radiation value on 21<sup>st</sup> June and 21<sup>st</sup> December

Mean Solar period in summer	6h18 (1702.9 m <sup>2</sup> )
Mean Solar period in winter	0h54 (1702.9 m <sup>2</sup> )
Mean Sky view factor (SVF)	3.5 %

Table 3: Modern area Heliodon calculation (Mean Solar period on 21<sup>st</sup> June (Summer) and 21<sup>st</sup> Dec (Winter) and Mean SVF)

## 5 Discussion:

We investigated sky Access versus shading for pedestrian comfort in the hot tropical climate of Jeddah. Our results show that 10% SVF at street level could be a good compromise, and that it could be a target for the new transition areas in the metro nodes.

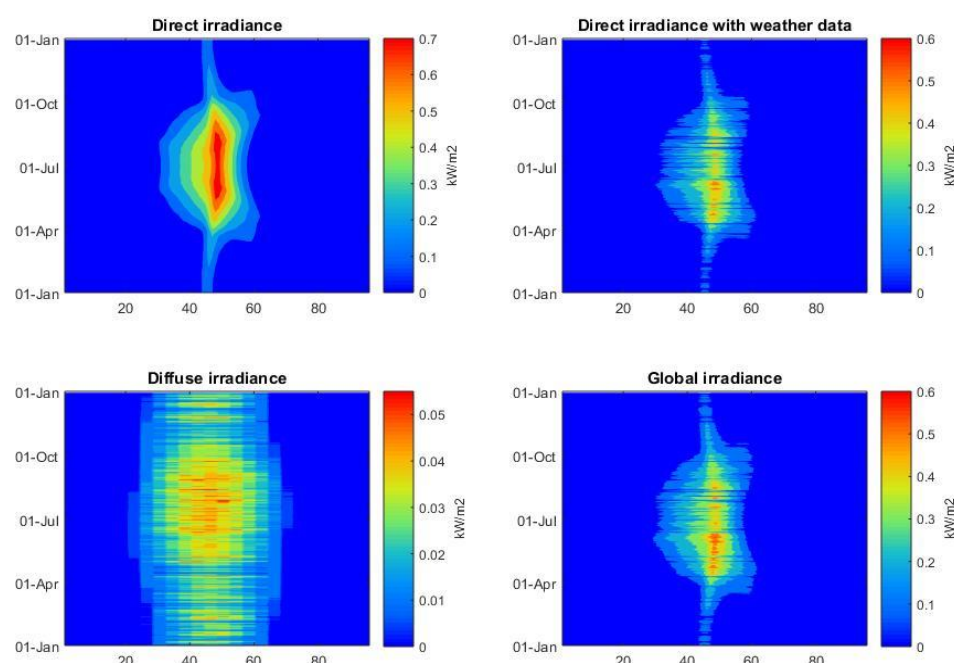


Figure 8: Solar Evolution Old area done by: Heliodon plus.

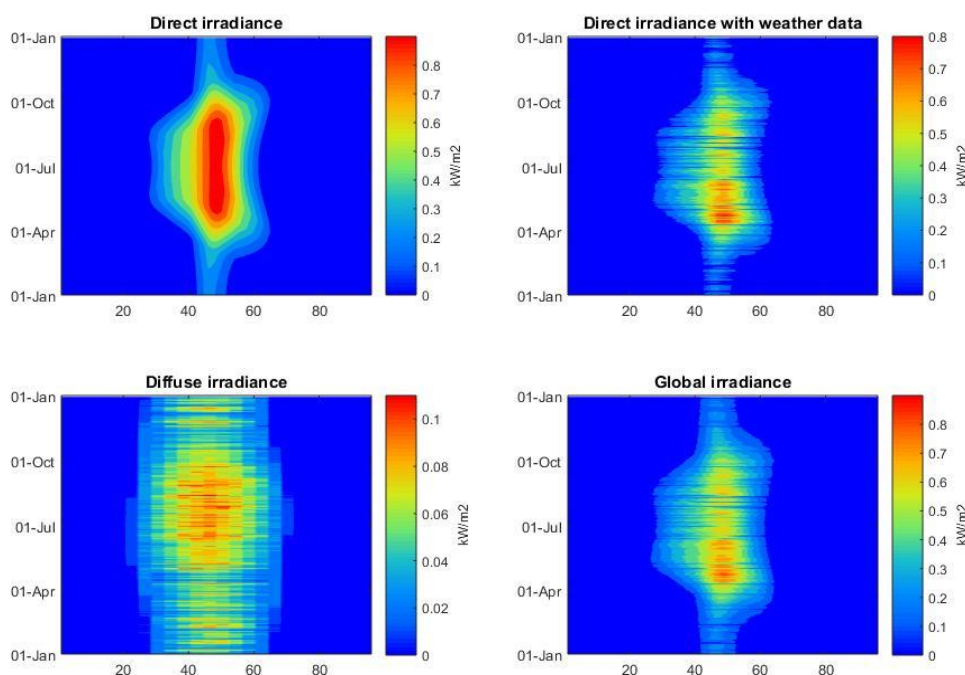


Figure 9: Solar Evolution Modern area (al Salamah) done by: Heliodon plus.

The study of the presence of clouds was obtained from the meteorological station, the theoretical energy data obtained are compared with Heliodon with actual data measured by the local weather station and a correction factor is established. Seeing the difference between the theoretical values and means of direct radiation, it proceeds to establish a correction factor with the following formula [Nahon 2016].

$$\text{Correction factor} = \frac{\text{Solar radiation calculated from the measured value}}{\text{Solar radiation calculated by Heliodon}}$$

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<b>Correction</b>	0.64	0.76	0.82	0.83	0.72	0.57	0.55	0.52	0.68	0.81	0.75	0.66

Table 4: Heliodon plus correction factor of each month.

## 6 Conclusion:

Our demonstration of the analysis of solar penetration, in both layouts in Jeddah city indicates and confirms the existence of the urban sprawl problem. Therefore, shading and densifying Jeddah city is essential, but a balance must be maintained. The idea is to consider the main stations of the future metro as nodes, creating more densely inhabited localities and also defining transitional spaces for pedestrian activities. Therefore, in continuing the study, we will model the extra extrusions on the facades of the old area, to evaluate their participation to shading.

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